Accepted (Peer-reviewed) for publication in NatureElectronics. The final authenticated version is available online at: https://www.nature.com/articles. DOI: 10.1038/s41928-020-0430-z

Cars as a tool for monitoring and protecting biodiversity

Modern cars have an array of sensors that allow different objects to be recognised, including large and small animals. They thus have the potential to become a tool for monitoring biodiversity and improving driver safety. But to achieve this — and create a global network of moving sensors — various challenges in computing, communications and privacy need to be addressed.

Fernando Ascensão, Cristina Branquinho, Eloy Revilla

Roads, like other transport infrastructures, allow goods and people to be efficiently transported and play a valuable role in economic development[1]. But roads also have a negative impact on biodiversity[2]. In particular, animal-vehicle collisions are an increasing issue as road networks expand and traffic volumes grow[3]. Such collisions are also a serious threat to drivers and passengers, causing significant injuries to people and damage to vehicles, with a high toll for the. society. Despite the differences between studies on how to estimate the costs related to collisions between vehicles and animals, considerable annual expenses have been reported, including (Mi US$) 406-545 in Sweden[4], 25 in Brazil[5], 1068-1409 in Texas, USA[6] or 232 in California[7].

Cars do though have an array of sensors that allow different objects to be recognised, including both large and small animal species. They thus have the potential to become a tool for monitoring biodiversity and conservation (Fig. 1). The information gathered by these monitoring systems could be fed, via the cloud, to global biodiversity databases of animal movement[8] and species distribution[9]. This could then, in turn, be used to update different ecological models, such as those on species distribution and migrations pathways. The gathered information could then also feedback to other vehicles and the relevant road network authorities in order to help improve driver safety and assist road developments. The volume and accuracy of the information that can be gathered by these car sensors could revolutionize environmental monitoring. But in order to turn cars into a global network of moving sensors, challenges in computing, communications and privacy will need to be addressed.

Car capabilities

The idea of cars collecting information has been in practice for decades, such as through the use of the Global Positioning System (GPS)[10], but modern cars now offer a range of sophisticated data collection capabilities. The availability of this technology has led to a number of recent proposals for using cars to collect different types of information[11,12]. For example, Google Street View vehicles have been equipped with pollution measurement sensors in order to reveal urban air pollution patterns[12]. The upsurge of wireless 5G networks and vehicular cloud computing[13] also means that the information collected by individual cars can be wirelessly transmitted to cloud servers for analysis and integration.

The car systems that target animal detection and recognition are rarely considered for wider exploitation. However, we believe that these systems have considerable potential as a research tool. Cars are being equipped with sensors such as cameras and lidar (light detection and ranging) technology, which in conjunction with machine learning algorithms, could enable the detection and identification of a wide range of animal species, yielding information such as location and movement behaviour[14]. This approach could be used with large mammals, but also with other smaller species. It could, for example, be used to monitor pond-breeding amphibians during migrations, reptiles thermoregulating on warm asphalt, butterflies and birds flying over the road, and small mammals crossing roads or moving in surrounding areas.

The sensors can also be used to detect and identify roadkill carcasses. This is perhaps more realistic for larger species because it is easier to recognize their distinct characteristics (long body-members, colour patterns, horns), though recent experiments with amphibians have provided encouraging resulsts[15]. Beyond existing capabilities, cars could also perhaps be equipped with other sensors such as ultrasound detectors, which could allow different species of bats to be recognized.

Monitoring animals on roads

Information about the location and behaviour of live animals near roads is important for understanding how animals react and respond to the presence of roads and traffic. In particular, it can help understand where different species choose to cross a road, the success of the crossing, and at what time of day and year they choose to cross. It can also be used to help understand the way species use roads and verges for displacement, foraging and hunting[16]. When available, this type of information is generally restricted to a few sections of road[17] and is thus difficult to generalize for an entire road network and ecosystem.

Cars could, with relative ease, collect this information and send it to remote servers for data processing, thus boosting the sampling effort and therefore our ability to detect movement and behaviour patterns across species. Central servers would could then also potentially inform vehicles and drivers, in real time, with relevant information, suggesting alternative routes or adjusting speed for the most problematic sections of the road. For example, when large mammals such as elk are detected, the system could help reduce the probability of an accident occurring.

Modelling landscape patterns

Data on animal sightings (location and time) could further be integrated within ecological and earth observation information to update fine-scaled species distribution and landscape connectivity models[18,19]. These models use environmental data — including climate (such as temperature and precipitation), water, and vegetation — to derive the most probable areas of occurrence and movement of a given species. Today, earth observation information collected on a daily basis from remote sensing satellites provide such detailed environmental data[20,21]. This could be combined with data gathered by car sensors, which could provide high accuracy maps of the probability of occurrence for a wide range of species across the entire road network.

The updated models could then also be used to inform car navigation systems, which could consider alternative routes or adjust speed in the most problematic road stretches, depending on the likelihood of animal-vehicle collisions occurring during travel. For example, the likelihood of massive pond-breeding amphibian migration occurring can be predicted based on water proximity, time period (year and day) and specific climate characteristics[22]. Likewise, migration routes of larger ungulates can be modelled[23]. And thus, with the right data, the likelihood of collisions could be greatly reduced. The high volume of data that can be collected by cars could lead to models from which information about where to install permanent mitigation measures, including road passages and exclusionary fences, could be extracted.

Information for passengers

The data gathered by cars could also be used to provide passengers with information about the current location of species inhabiting a given region, and the probability of sightings occurring according to the date and time of day. This is relevant to anyone interested in biodiversity such as when someone is visiting a natural park. Car passengers could also be warned when entering the area where an endangered species is present, leading the driver to adopt a more defensive and cautious driving approach.

In some protected areas, visitors are allowed to drive only along determined roads and have to remain safely inside vehicles. This is the case, for example, in Kruger National Park in South Africa and Yellowstone National Park in the US. The information gained from the car sensors could be used in such contexts to help manage the balance between visitors having the opportunity to see particular animals and their presence — and cars — disturbing the animals.

Challenges

Turning cars into biodiversity monitoring tools does involve a number of data transmission and communication challenges. To start, sending all the information collected by car sensors to remote servers is not feasible[11], given the amount of data potentially collected in short time intervals. Pre-processing and aggregation of the data will be required. But the specific architecture of this system remains to be determined, and the software and hardware of it must also offer easy implementation and low maintenance[13].

The exchange of information between the vehicles and the servers needs to occur at high speed, in order to detect, process and eventually react in short time intervals. Different systems from different car companies must also be compatible, either by communicating to common servers or by allowing interchange of information between servers. Furthermore, the additional sensors and data processing will lead to further energy consumption by the car, and this will need to be kept to a minimum. One possible solution would be to integrate the data processing and information exchange processes into a driver's smartphone, or similar device, taking advantage of the high computing capacity of these machines and the capabilities of the Internet of Things[24]. The desired effective interoperability also entails major security and privacy challenges, requiring an attack-resilient system, highly efficient but secure data exchange, and customer privacy guarantees (that is, within an adequate legal framework)[25].

Finally, upgrading cars with this technology should not involve extensive costs, with the risk that consumers refrain from equipping the car with such systems. The message to consumers, businesses, and decision makers should be that the extra cost will pay off in the long term: reducing animal-vehicle collisions saves money, notably on insurance and health systems, and damaged vehicles.

Outlook

There is shortly expected to be over two billion cars in the world, circulating on a road network that is rapidly expanding[26,27] particularly in Africa and Asia[28]. A significant proportion of these vehicles will have total or partial automated navigation systems[29]. We expect that the rapid development of sensor technology, machine learning algorithms, and 5G networks will allow car navigation systems to detect, identify and communicate the location of different animal species. The data that can be gathered from these car sensors could improve the permeability of roads to animal movement and play a key role in the development of new roads.

Fernando Ascensão[1,2], Cristina Branquinho[1], Eloy Revilla[2]
[1]Ce3C - Centre for Ecology, Evolution and Environmental Changes – Faculdade de Ciências da Universidade de Lisboa, Portugal
[2]Department of Conservation Biology, Estación Biológica de Doñana (EBD-CSIC), Sevilla, Spain
e-mail: fjascensao@fc.ul.pt

Acknowledgements

André Sentieiro is acknowledged for developing the image and design. Marcello D'Amico is acknowledged for comments and inputs on an early version of the manuscript.

References

1. Dulac, J. Global land transport infrastructure requirements: estimating road and railway infrastructure capacity and costs to 2050. *International Energy Agency*, 1–54 (2013).
2. Van der Ree, R., Smith, D. J. & Grilo, C. Handbook of road ecology (John Wiley & Sons, 2015).
3. González-Suárez, M., Zanchetta Ferreira, F. & Grilo, C. Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography* **27**, 1093–1105 (2018).
4. Gren, I.-M. & Jägerbrand, A. Calculating the costs of animal-vehicle accidents involving ungulate in Sweden. *Transportation Research Part D: Transport and Environment* **70**, 112–122 (2019).
5. Abra, F. D. *et al.* Pay or prevent? Human safety, costs to society and legal perspectives on animal-vehicle collisions in São Paulo state, Brazil. *PLoS One* **14**, (2019).
6. Wilkins, D. C., Kockelman, K. M. & Jiang, N. Animal-vehicle collisions in Texas: How to protect travelers and animals on roadways. *Accident Analysis & Prevention* **131**, 157–170 (2019).
7. Shilling, F., Waetjen, D., Harrold, K. & Student, P. *Impact of Wildlife-Vehicle Conflict on California Drivers and Animals*. (2019).
8. Kranstauber, B. et al. The Movebank data model for animal tracking. *Environmental Modelling & Software* **26**, 834–835 (2011).
9. Flemons, P., Guralnick, R., Krieger, J., Ranipeta, A. & Neufeld, D. A web-based GIS tool for exploring the world's biodiversity: The Global Biodiversity Information Facility Mapping and Analysis Portal Application (GBIF-MAPA). *Ecological Informatics* **2**, 49–60 (2007).
10. Ahn, K. & Rakha, H. The effects of route choice decisions on vehicle energy consumption and emissions. *Transportation Research Part D: Transport and Environment* **13**, 151–167 (2008).

11. Massaro, E. et al. The Car as an Ambient Sensing Platform. *Proceedings of the IEEE* **105**, 3–7 (2017).
12. Apte, J. S. et al. High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Environ. Sci. Technol.* **51**, 6999–7008 (2017).
13. Coutinho, R. W. L., Boukerche, A. & Loureiro, A. A. F. Design Guidelines for Information-Centric Connected and Autonomous Vehicles. *IEEE Communications Magazine* **56**, 85–91 (2018).
14. Mammeri, A., Zhou, D., Boukerche, A. & Almulla, M. An efficient animal detection system for smart cars using cascaded classifiers. *2014 IEEE International Conference on Communications (ICC)*, 1854–1859 (2014); https://doi.org/10.1109/ICC.2014.6883593
15. Sillero, N., Ribeiro, H., Franch, M., Silva, C. & Lopes, G. A road mobile mapping device for supervised classification of amphibians on roads. *Eur. J. Wildl. Res*. **64**, 77 (2018).
16. D'Amico, M., Périquet, S., Román, J. & Revilla, E. Road avoidance responses determine the impact of heterogeneous road networks at a regional scale. *Journal of Applied Ecology* **53**, 181–190 (2016).
17. Ascensão, F. et al. Inter-Individual Variability of Stone Marten Behavioral Responses to a Highway. *PLOS One* **9**, e103544 (2014).
18. McRae, B. H., Dickson, B. G., Keitt, T. H. & Shah, V. B. Using circuit theory to model connectivity in ecology, evolution, and conservation. *Ecology* **89**, 2712–2724 (2008).
19. Elith, J. & Leathwick, J. R. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annual Review of Ecology, Evolution, and Systematics* **40**, 677–697 (2009).
20. Pettorelli, N. et al. Framing the concept of satellite remote sensing essential biodiversity variables: challenges and future directions. *Remote Sensing in Ecology and Conservation* **2**, 122–131 (2016).
21. Schneider, F. D. et al. Mapping functional diversity from remotely sensed morphological and physiological forest traits. *Nat. Commun.* **8**, 1–12 (2017).
22. Timm, B. C., McGarigal, K. & Compton, B. W. Timing of large movement events of pond-breeding amphibians in Western Massachusetts, USA. *Biological Conservation* **136**, 442–454 (2007).
23. Baltensperger, A. P. & Joly, K. Using seasonal landscape models to predict space use and migratory patterns of an arctic ungulate. *Movement Ecology* **7**, 18 (2019).
24. Aloi, G. et al. Enabling IoT interoperability through opportunistic smartphone-based mobile gateways. *Journal of Network and Computer Applications* **81**, 74–84 (2017).
25. Weber, R. H. Internet of Things – New security and privacy challenges. *Computer Law & Security Review* **26**, 23–30 (2010).
26. Gross, M. A planet with two billion cars. *Current Biology* **26**, R307–R310 (2016).
27. Meijer, J. R., Huijbregts, M. A. J., Schotten, K. C. G. J. & Schipper, A. M. Global patterns of current and future road infrastructure. *Environ. Res. Lett.* **13**, 064006 (2018).
28. Ascensão, F. et al. Environmental challenges for the Belt and Road Initiative. *Nat. Sustain.* **1**, 206–209 (2018).
29. Gao, P., Kaas, H.-W., Mohr, D. & Wee, D. Automotive revolution–perspective towards 2030 How the convergence of disruptive technology-driven trends could transform the auto industry. Advanced Industries, McKinsey & Company (2016).

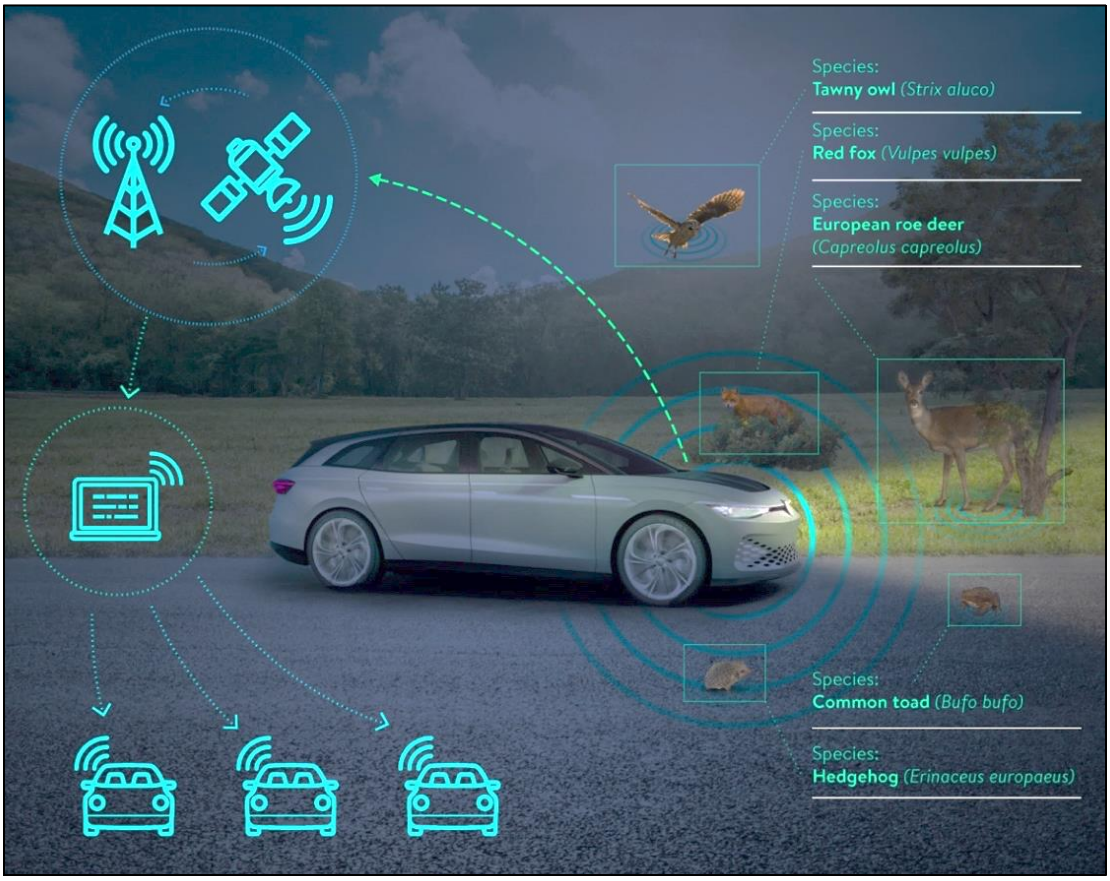

Fig. 1. **Cars as a global network of moving sensors.** Conceptual illustration of a car detecting — and identifying — different animal species on, and in the vicinity of, a road. This information is then transferred to servers that could update in real-time different biodiversity databases and ecological models. Relevant information from the output of these model can then also sent back to cars in order help avoid accidents. (Design by André Sentieiro.)